Geochemical characterization of volcanic glass from Pu‘u Wa‘awa‘a, Hawai‘i Island

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Abstract

New fieldwork and laboratory research are reported here to help better define a major source of volcanic glass in the Hawaiian Islands: Pu‘u Wa‘awa‘a volcanic cone. This research centers on two questions: (1) What is the size of raw material available at the source and how does this parent material compare with debitage in archaeological collections? And, (2) Can chemical variably in Pu‘u Wa‘awa‘a volcanic glass allow us to sub-classify artifacts? As one would expect, average size and weights are predictably smaller when comparing raw material to primary reduction, and smaller again when comparing primary reduction to core reduction. XRF chemical characterisation shows that while all volcanic glass derived from Pu‘u Wa‘awa‘a is chemically similar, it is possible to sub-classify artifacts by copper (Cu) content. The vast majority of artifacts made from Pu‘u Wa‘awa‘a volcanic glass are from Cu-poor eruptions. There are, however, rare examples of Cu-rich artifacts. The frequency of Cu-rich artifacts increases with distance from source. One explanation for this enigmatic pattern is that it is the by-product of a process similar to serial founder effect. Cu-rich flaking cores could have increased in relative proportion as the total amount of Pu‘u Wa‘awa‘a glass in assemblages became smaller at sites further distant from the source. Alternatively, this pattern may simply reflect the general pattern of increased fragmentation of Pu‘u Wa‘awa‘a cores as they are passed further down the line. Interestingly, in the South Point region we do not find any examples of Cu-rich material, again suggesting a pattern of access and exchange similar to the closest sites to the source.

Introduction

The assignment of archaeological artifacts to a geological source relies on our knowledge of that source’s geological history, local geomorphology, and within-source geochemical variation (e.g., Mills et al. 2008). New fieldwork and laboratory research are reported here to help better define a major source of volcanic glass in the Hawaiian Islands: Pu‘u Wa‘awa‘a[1] volcanic cone. Located on the northern flanks of

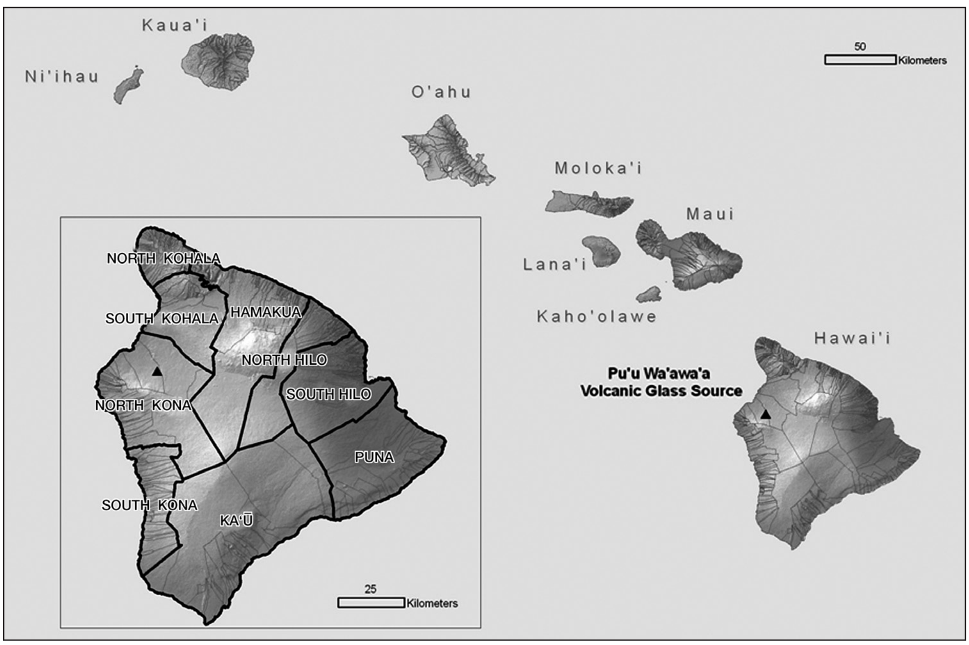

Figure 1. Location of a major volcanic glass source: Pu‘u Wa‘awa‘a, Hawai‘i Island.

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Hualalai volcano on Hawai'i Island, Pu'u Wa'awa'a, meaning 'furrowed hill,' is a horseshoe-shaped, trachyte volcanic cone that is 1.6km in diameter and 245m high (Figure 1). It was built up by a series of eruptions dated to 114 to 92 kya (see Cousens et al. 2003 for a recent review). The northern face is incised with gullies exposing pumice beds containing pebble-to-cobble sized glass fragments (Clague and Bohrson 1991: 440), which are the only known source of "large chunks of glass" in the island group (Macdonald et al. 1983: 124; see also Weisler 1990) (Figures 2 and 3).

This research centers on two questions relevant for archaeological studies of lithic technology and sourcing: (1) What is the size of raw material available at the source and how does this parent material compare with debitage in archaeological collections? And, (2) Given that the dome formed from multiple eruption events, can chemical variability in Pu'u Wa'awa'a volcanic glass artifacts allow us to define sub-groups?

Background

The Archaeology of Volcanic Glass in Hawai'i

The flake-and-core method of expedient tool production in the Hawaiian Islands is evident from the earliest deposits containing volcanic glass artifacts (Schousboe et al. 1983), to the post-contact era when these same techniques were applied to bottle glass (Bayman 2009; Flexner 2010). Following a short-lived enthusiasm for obsidian hydration dating in the 1970s and 1980s (see Tuggle 2009 for a retrospective), and attempts at visual sourcing (Olsen 1983), Weisler (1990) was the first to apply XRF (x-ray fluorescence) to the problem of sourcing Hawaiian volcanic glass. These initial results did not encourage a great deal of new research since potential natural sources numbered in the hundreds and individual quarry sites were largely unknown.

New research on volcanic glass has begun to address key gaps in our understanding of volcanic glass quarrying. Williams (2004) described a chilled-glass surface quarry (called the Pohakuloa Chill Glass Quarry Complex) on a relatively recent Mauna Loa flow (1650-1750 AD) over an area of approximately 4,050ha. He noted that within the intensively surveyed portion of flow (k4) which produced the chilled-glass, there are 12 locations where quarrying is clearly evident. These sites have a combined area of 170ha with the largest (50-10-30-21666) made up of 366 discrete features spread over 146.5ha (Williams 2004: 110).

McCoy et al. (2011) used XRF and lithic technology analysis on 3,329 volcanic glass artifacts from 87 sites throughout the major islands in an assessment of access to, and exchange of, Pu'u Wa'awa'a volcanic glass in the largest lithic sourcing study to date in the Hawaiian Islands. Our aim was to advance "landscape archaeology through a cost-surface analysis scaled to understand the logistics of quarrying and exchanging volcanic glass" (McCoy et al. 2011: 4). We found that territorial boundaries do not appear to

Figure 2. Base of Pu'u Wa'awa'a volcanic cone's signature north face gullies.

Figure 3. Close up of pumice bed with natural volcanic glass fragment shown *in situ* (center, left of root).

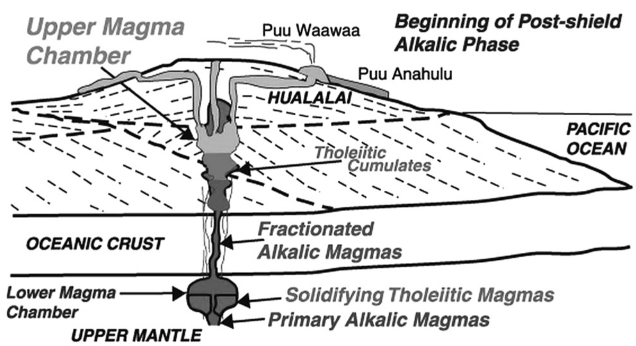


Figure 4. The geological history of Pu'u Wa'awa'a (from Cousens et al. 2003, Figure 9).

have effectively restrained quarrying or exchanges between neighbors, but that volcanic glass was not commonly part of activities beyond a single day's travel.

Pu'u Wa'awa'a Geology and Geochemistry

The geological history of Pu'u Wa'awa'a, schematically represented in Figure 4, has also been the topic of recent work (Cousens et al. 2003), including a deep well geological core that cross-cut multiple eruptions (Table 1; Mills et al. 2011). Today, there is a modern quarry on the east side of the dome where one can observe pumice bed deposits, some of which are also exposed in gullies along the north face of the dome. We presume it is from these north face gullies that people quarried material in the past.

If we look at an example of the geochemistry from a core that cross-cuts flows associated with Pu'u Wa'awa'a eruptions, we see that trachyte eruptions are easy to recognize when compared with basalts and that Pu'u Wa'awa'a trachytic glass is distinct from the more common Hawaiian basaltic glass (Figure 5). In terms of trace elements, trachyte eruptions from Pu'u Wa'awa'a reported in Mills et al. (2011) are indistinguishable from one another with the exception of having remarkably different concentrations of copper (Cu). Stone and Fleet (1991: 1363) have described similar variation in Cu for recent eruptions of the Kilauea Iki lava lake with Cu-rich sulfide due to "a lower temperature of quenching and more extensive annealing and crystallization history of the lava."

Geological Sampling of the Pu'u Wa'awa'a Volcanic Dome

A pedestrian survey was conducted to identify and collect geological samples of natural volcanic glass in gullies at locations along two transects spanning the north slope to the base of Pu'u Wa'awa'a (Figure 6; McCoy 2010). Collection locations were recorded by GPS (Trimble GeoXT and Juno). No excavations were conducted; *in situ* samples were removed from naturally exposed cuts. In total, 95 sizable pieces were collected from the beds within four hours.[2]

Along Transect 1, pumice beds had roughly the same strike (compass direction of bed) with an average of around 215° southwest (Figure 6). The dip (downward angle of beds) was slightly different from top to bottom, with beds steeper at the top (55°-40° downward angle) and more gradual towards the bottom (33°-29° downward angle). Volcanic glass nodules were discovered at each of the locations noted along the two transects. These appear to be a good representation of the range in size and quality of material available for lithic tool manufacture in the past. The natural distribution of volcanic glass was found to be strictly limited in geographic range with few examples noted in the colluvial zone at the base of the north face. Geological samples are now part of the reference collections housed at the University of Otago archaeological laboratories.

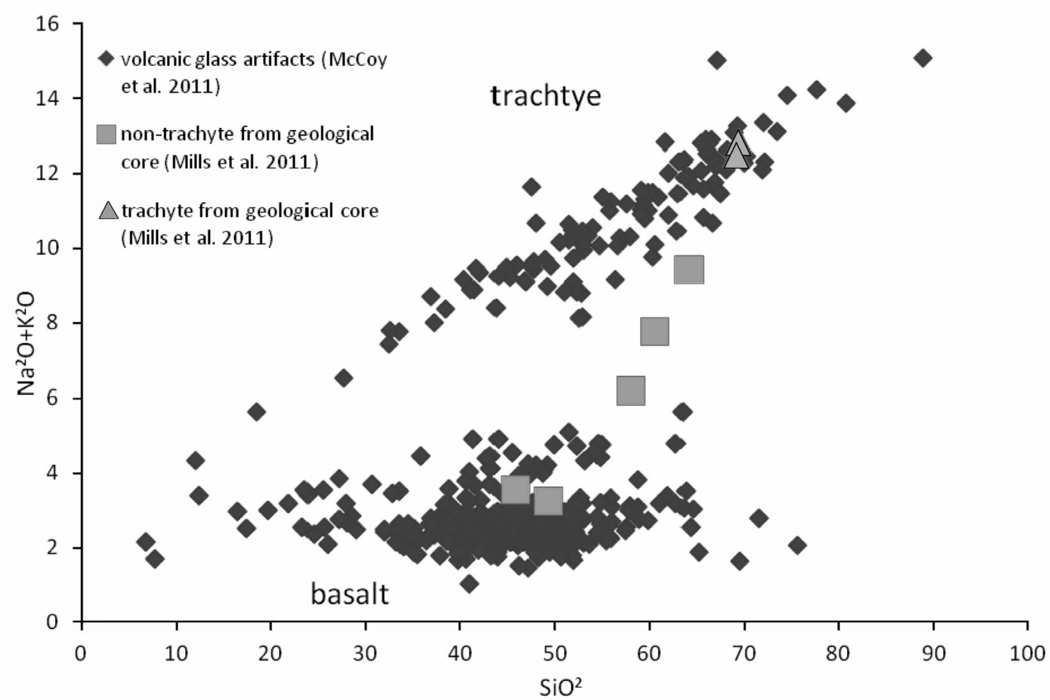


Figure 5. Geochemical classification of volcanic glass artifacts (McCoy et al. 2011) and geological core with examples of basalt and basaltic glass, trachyte and trachytic glass from Pu'u Wa'awa'a eruptions, and several geological samples from transitional material.

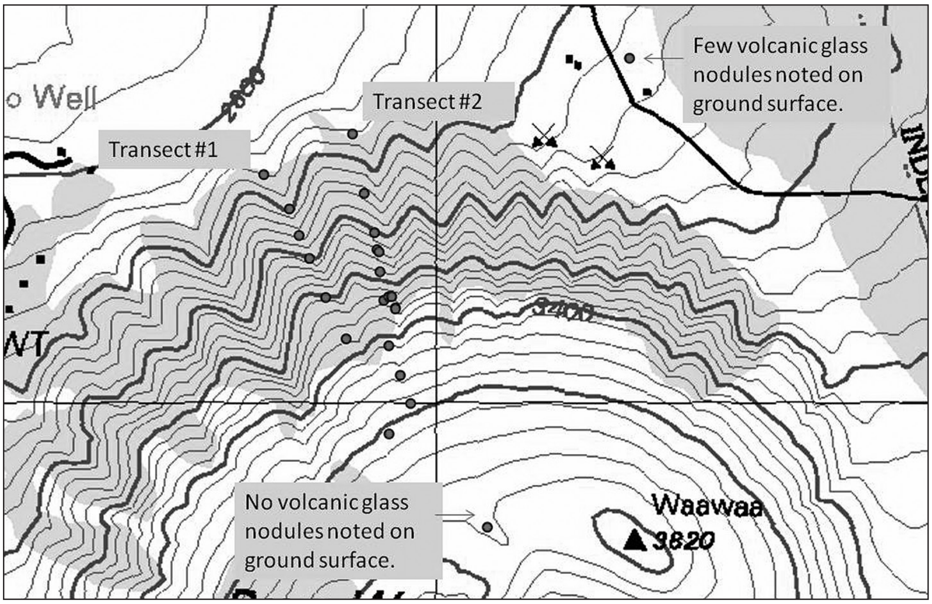


Figure 6. Geological survey of Pu‘u Wa‘awa‘a volcanic glass (from McCoy 2010).

Assessment of Raw Material Size

Most lithic technology analyses are rooted in the fact that the process of creating something from stone is reductive with raw material quarried, usually shaped by knapping, used, and often retooled, with discard at every stage. The upper size limit of flaked debitage from the first stage of reduction is dictated by the size of raw parent material. Similarly, in a core-and-flake technology, like that applied to volcanic glass in the Hawaiian Islands, the size of secondary flaked debitage is dictated by the size of cores. Therefore, the average size and weight of debitage should generally follow from the stages of reduction represented.

A total of 95 pieces of volcanic glass judged to be of high enough quality and large enough to be considered potential raw material were measured and weighed.[3] Table 2 gives these values compared with debitage sourced to Pu‘u Wa‘awa‘a from three coastal areas: ‘Anaeho‘omalu (Ha-E1-148, South Kohala District), an estimated 7.4 hours (17km) round-trip hike from site-to-source; Puapua (Ha-D7-83, North Kona District) 11.3 hours (23km) round-trip; and South Point (Ha-B21 & Ha-B22, Ka‘ū District) a distant 40 hours (95km) round-trip (Figure 7). A lithic technology analysis has suggested that more primary reduction was conducted at ‘Anaeho‘omalu, whereas people living at Puapua may have received much of their Pu‘u Wa‘awa‘a material as cores in primary exchanges with those who had direct access to the source (McCoy et al. 2011). South Point is an anomaly. The sites there are the most distant locations where Pu‘u Wa‘awa‘a glass has been discovered, but the technology is consistent with direct access.

As one would expect, average size and weights are predictably smaller when comparing raw material to primary reduction at ‘Anaeho‘omalu, and smaller again when comparing primary reduction to core reduction at Puapua (Figure 8). Initial working of the material results in debitage that is roughly 1/10th of the average weight of raw blocks of glass. Next, reduction of cores with the goal of producing the maximum number of usable flakes results in pieces being on average less than half the weight of primary debitage. At South Point, debitage is again closer in size and weight to ‘Anaeho‘omalu than to Puapua, supporting the notion that these assemblages represent a type of non-local direct access.

Geochemical Variation of Pu‘u Wa‘awa‘a Volcanic Glass Artifacts

EDXRF is a non-destructive method for sourcing volcanic glass that has been used in Hawai‘i for over twenty years (Weisler 1990). New analyses reported here were completed at the University of Otago. The BrukerAXS™ EDXRF protocol used in the present analysis follows current best practices for using portable XRF (see Shackley 2010). Optimal settings for ‘mid-z’ trace elements, particularly Rb, Sr, Y, Zr, and Nb, were used. A pelletized USGS basalt standard (BHVO-2) was used as a control. Instrument settings were similar to previous studies (McCoy et al. 2010, 2011; Mosley and McCoy 2010); a 300 second run time (40eV per channel, filament ADC = 8.0 amp) with a filter (12 mil Al + 1 mil Ti + 6 mil Cu). CalProcess software was used for quantification drawing upon the same international standards used to calibrate peak intensities at the University of Hawai‘i, Hilo EDXRF Laboratory (Lundblad et al. 2011); a 500 second run time was used for standards.

	Cu ppm	Rb ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm
Cu-Poor Eruption, Geological Core (Cat. # 4458-02 1440 ft LIGHT)	4	118	20	77	870	124
Cu-Rich Eruption, Geological Core (Cat. # 4458-02 1570-1580 ft)	141	119	25	73	836	120

Table 1. Mid-z elements and Cu values for trachyte in core cross-cutting Pu‘u Wa‘awa‘a geological history (Source: Mills et al. 2011).

	weight (g)	length (mm)	width (mm)	height (mm)	n
Pu‘u Wa‘awa‘a Geological Samples	127.99	56.27	43.01	33.91	52
‘Anaeho‘omalu (Ha-E1-148, South Kohala District)	1.64	17.06	13.40	6.50	71
Puapua (Ha-D7-83, North Kona District)	0.64	13.74	10.40	4.38	35
South Point (multiple sites, Ka‘ū District)	1.84	20.25	14.69	5.19	10

Table 2. Average size and weight of geological samples and debitage sourced to Pu‘u Wa‘awa‘a from three coastal areas: ‘Anaeho‘omalu, Puapua, and South Point.

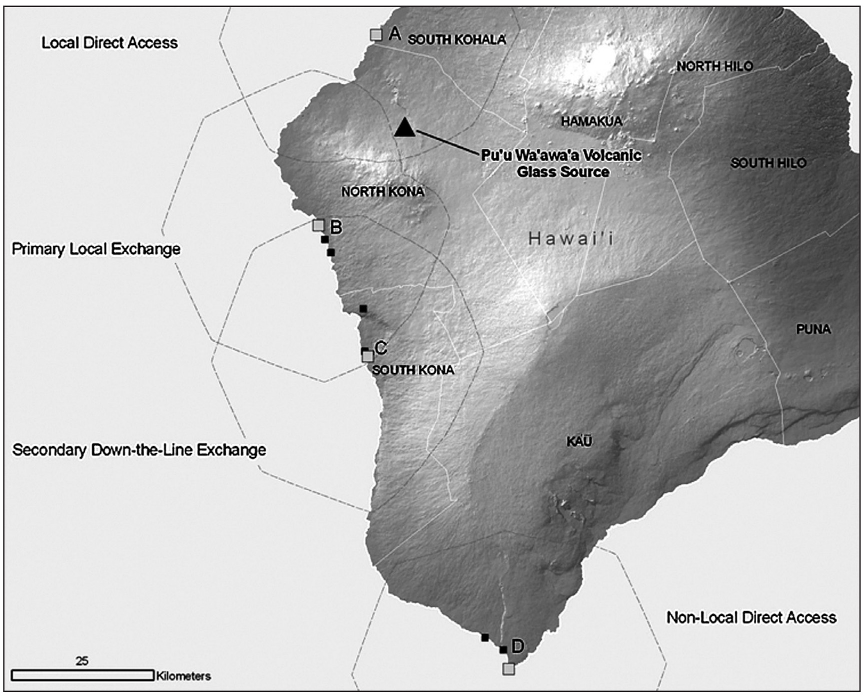


Figure 7. Model of access and exchange of Pu‘u Wa‘awa‘a volcanic glass (McCoy et al. 2011). This map shows sites with buffers around them that estimate the area one could travel (roundtrip) in a single day. At Site A (‘Anaeho‘omalu), people could have made local direct access day trips to the source as well as to within the daytrip buffer of Site B (Puapua; note that Kahalu‘u is not far from this location) where cores could be passed along. Site B is well placed to not only for people to obtain volcanic glass from primary local exchanges with those who directly accessed the material, but to make secondary exchanges with people to the south living near Site C (Honaunau), beyond the day trip buffer of Site A. The southern end of the Site C buffer is roughly where the linear decay predicts the source to no longer appear in assemblages. Site D (South Point) in the Ka‘ū District represents sites where we have a low frequency of the source, but the technology is most similar to Site A. The source was directly accessed, possibly by a combination of hiking and sailing, in an example of non-local direct access.

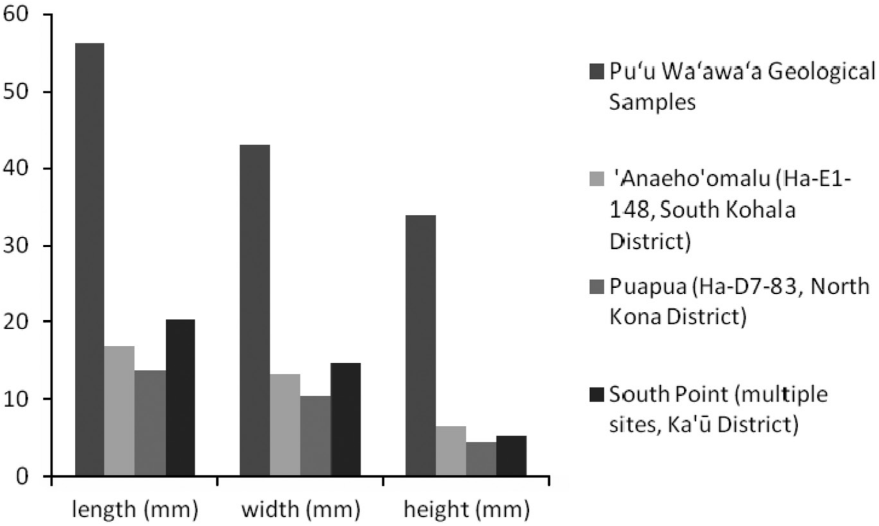


Figure 8. Average size (mm) of Pu‘u Wa‘awa‘a glass. Geological samples (n=95) representing raw material are clearly the largest on average. Assemblages representing direct access are next largest (‘Anaeho‘omalu and South Point) with the core reduction assemblage the smallest (Puapua).

Geochemical studies of flows associated with Pu‘u Wa‘awa‘a suggest that we should find at least two groups: one Cu-poor and the other Cu-rich. Interestingly, all the geological samples collected have low Cu, suggesting Cu-rich volcanic glass flows were either rare, or pumice beds with this material are rarely exposed in north face gullies today (Table 3).

While Cu-rich eruption Pu‘u Wa‘awa‘a samples were not collected on the brief visit to the source described here, there are indications that this type of material was on rare occasion available in the past. A small number of Cu-rich eruption volcanic glass artifacts were found at three sites; accounting for between ca. 1.6% to 5% of the total number of Pu‘u Wa‘awa‘a artifacts from each site (Table 4). The few Pu‘u Wa‘awa‘a artifacts discovered in the South Point region (n=38) do not include any Cu-rich samples.

Discussion

The discovery that the vast majority of artifacts made from Pu‘u Wa‘awa‘a volcanic glass are from Cu-poor eruptions is not unexpected given that today, the glass most accessible for quarrying was found to be Cu-poor glass. However, the rare examples of Cu-rich eruption artifacts found at sites may have a great deal to tell us about larger patterns of quarrying and exchange. If we examine the results in terms of distance to source, we find the seemingly inexplicable pattern of increasing frequency of Cu-rich eruption Pu‘u Wa‘awa‘a volcanic glass with the increased distance from the source (Figure 9). Why should we see this geographic pattern in a sub-source that is extraordinarily rare?

One explanation for this enigmatic pattern is that it is the by-product of a process similar to serial founder effect. Founder effect is a principle of genetics that describes the loss of variation that occurs when a small subset of population breaks off to form a new group. In this case, the ‘Anaeho‘omalu assemblage is most likely to closely mirror the naturally occurring population since the technological analysis suggests that this assemblage represents regular, direct access. Based on this, it appears likely that Cu-rich glass was rarely accessible, accounting for only 1.6% of Pu‘u Wa‘awa‘a glass at the site. Next, if a selection of cores were exchanged out to Puapua, a short distance away, then as they entered the exchange network there would have been an opportunity for cores made from Cu-rich glass to be over represented, or under represented, as compared with their frequency in primary debitage. The Cu-rich glass artifacts at Puapua were only 2.2% of all Pu‘u Wa‘awa‘a glass artifacts, and as such they would have still been exceedingly rare. As cores were passed further down the line to Honaunau there would have been even more opportunities for down the line exchanges to increase the relative frequency of this rare sub-group, which jumps to 4.7%.

Alternatively, the amount of Cu-rich material could be similar across sites and the increase in the relative frequency may simply be part of the more general spatial pattern of lithic reduction, specifically the fragmentation of late reduction stage cores (i.e., material is broken in to more, smaller pieces). Naturally, both of these factors could be at play simultaneously with slightly more Cu-rich cores passed down the line, which were in turn broken into increasingly more fragments as cores became exhausted. More individual artifact study may help pull apart these processes.

The absence of Cu-rich Pu‘u Wa‘awa‘a glass in samples tested from South Point may simply be due to the small

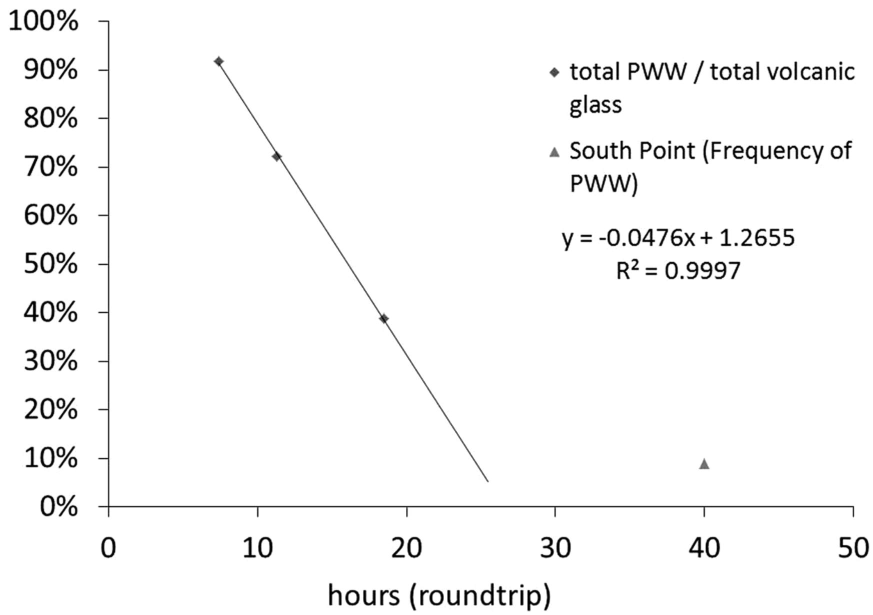
	K	Ba	Ti	Mn	Fe	Co	Ni	Cu	Zn	Ga	Pb	Th	Rb	Sr	Y	Zr	Nb
Geological Samples (Cu-poor) (ppm)	55841	1343	2458	1048	26512	11	29	29	146	26	16	12	118	37	47	1061	99
SD	10439	104	386	329	3071	2	22	10	13	2	2	3	7	4	2	64	5
Artifacts (Cu-poor) (ppm)	42409	1292	2020	937	27708	10	12	24	144	26	18	17	117	37	48	1031	96
SD	11349	96	356	54	1928	2	21	11	14	2	4	8	7	4	2	52	5
Artifacts (Cu-rich) (ppm)	47436	1243	2675	901	25505	11	65	79	123	23	21	21	116	35	46	1019	93
SD	909	34	118	15	1483	1	26	24	13	2	7	11	13	0	2	34	3

Table 3. Average values for geochemistry for Pu‘u Wa‘awa‘a geological samples and artifacts. All values are from University of Otago lab. Cu-rich artifacts were identified in UH Hilo data (McCoy et al. 2011) by using ratio of Cu to Y that show values well over 1.0.

	Distance to source (one way in km, round-trip travel time)	Frequency of PWW	Cu-rich Eruption (n)	Cu-poor Eruption (n)	Total PWW (n)	Frequency of Cu-rich PWW	Ratio (Cur-rich: Cu-poor)	Lab
‘Anaeho‘omalu (Ha-E1-148, South Kohala District)	17 km / 7.4 hours	91.7%	2	126	128	1.56%	1 : 63	Otago
Puapua (Kahaluu, -7702, North Kona District)	23 km / 11.3 hours	72.2%	4	176	180	2.22%	1 : 44	UH Hilo
Honaunau (Keoneele Cove, South Kona District)	40.3 km / 18.5 hours	38.7%	6	122	128	4.69%	1 : 20	UH Hilo
South Point (multiple sites, Ka‘ū District)	95 km / 40 hours	8.8%	0	38	38	0%	-	UH Hilo and Otago
			12	462	474			

Table 4. Frequency of artifacts from Cu-poor and Cu-rich eruptions. Sources: Otago data reported here, UH Hilo data from McCoy et al. 2011.

(a)



(b)

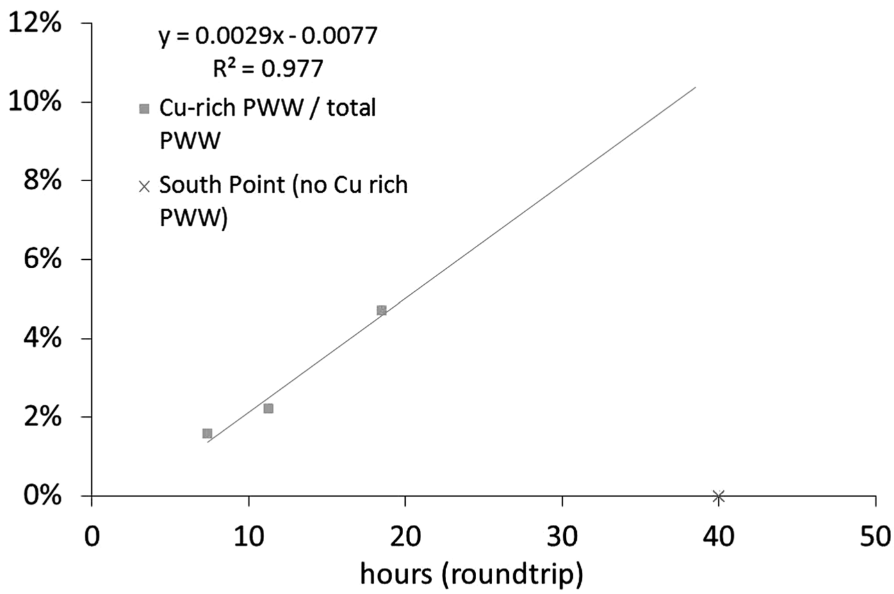


Figure 9. Frequency of all Pu‘u Wa‘awa‘a volcanic glass at sites, (a) sharply decreases with distance from source shown here as round trip travel time in hours. (b) Rare examples of Cu-rich Pu‘u Wa‘awa‘a glass increase in their relative frequency (shown here as percent of total Pu‘u Wa‘awa‘a glass). At South Point sites, the furthest known assemblage with Pu‘u Wa‘awa‘a, no examples of Cu-rich are found even though the predicted relative frequency should be higher than other assemblages where it was found. This result is consistent with a previous study that classified South Point assemblages as representing a different pattern of access and exchange (McCoy et al. 2011).

sample size. But on face value, these results are another indication that South Point assemblages represent direct access to the source. As noted previously (McCoy et al. 2011), the frequency of cortex, flake size, and frequency of wasted cores at South Point is similar to ʻAnaehoʻomalu. If sub-group frequencies are also similar to ʻAnaehoʻomalu where we find a ratio of 1:63 (Cu-rich:Cu-poor), then it is not surprising that no Cu-rich artifacts were found. But if people living at South Point received Puʻu Waʻawaʻa glass from down the line exchanges, then the absence is harder to explain since we would expect a frequency of Cu-rich glass of greater than 4.7% and perhaps closer to 10% or higher.

Notes

1. This location is also spelled as one word: Puʻuwaʻawaʻa.
2. Additional samples were collected from the colluvium within gullies, but this material was not used in this study since it was found out of its geological context.
3. An arbitrary lower size limit of 3cm in length for raw material was chosen since pieces naturally smaller than this size appeared unlikely to have been an appropriate size for flaking.

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